That the balance between supplies of moisture and nitrogen is important in the efficiency of moisture use by winter wheat was demonstrated in 1954–1955 by R. E. Ramig at North Platte, Nebr. In each season, 5.75 inches of available moisture in the soil at seeding time was best from the standpoint of efficiency of water use. The efficiency, however, varied widely in the two years and with the rate of nitrogen fertilization. In 1954, a year when seeding-to-harvest precipitation measured only 8.9 inches, the highest efficiency of 1.85 bushels per inch of water used was realized when 40 pounds of nitrogen fertilizer was applied to the acre. In 1955, when precipitation during the crop season was 17.1 inches, the top efficiency was 2.3 bushels per inch of water used, but that occurred when 80 pounds of nitrogen an acre was applied. In both years, as the applied nitrogen rate was reduced from those giving the highest efficiencies, the grain produced per inch of water used also was less. Without nitrogen fertilizer, only 0.9 bushel in 1954 and 1.1 bushels in 1955 were produced per inch of water. Each year, the efficiency of water use was approximately doubled by adjusting the nitrogen supply to a level that made possible the best use of stored and seasonal moisture.

Lack of other nutrients also lowers the efficiency of water use by plants. C. O. Stanberry and his coworkers in a study at Yuma, Ariz., in 1949–1952 showed that the combined 4-year yield of alfalfa varied from 25.8 to 50.0 tons an acre, depending on the quantities of irrigation water and phosphorus fertilizer applied. Efficiency of water use varied nearly 100 percent among different phosphorus treatments. It was 7.8 acre-inches per ton of hay when 800 pounds of P_2O_5 per acre were applied during the 3-year period and 14.2 acre-inches per ton when only 100 pounds of P_2O_5 were applied. The results substantiate the importance of adequate soil fertility in achieving the goal of maximum conservation of soil moisture.

Irrigation in Arid Regions

Wayne D. Criddle and Howard R. Haise

A farmer has to bear six factors in mind when he plans to irrigate his land. They are: The adequacy, reliability, and quality of the water supply; the control and conveyance of water; water requirements, including consumptive use, effective rainfall, net irrigation requirement, and irrigation efficiency; application of water; drainage for removal of both surface and subsurface excess water; and institutional arrangements.

Existing rights and uses must be respected. The fact that water flows past a man's farm does not necessarily give him the right to divert the waters and use them for irrigation. Downstream users may have established rights to the waters in accordance with State laws. If the flow is insufficient to meet all needs, the first appropriators may be entitled to receive their water first. Domestic and municipal uses also may have first priority. Irrigation, power, industry, navigation, wildlife, and recreation may have lower priorities.

The source of irrigation water usually is the rain and snow that falls on the watershed above. It may flow down to the valley in surface streams that can be stored or diverted for use, or it may travel underground and have to be pumped up. Occasionally the source is the ground water reservoir under the cropped land. Seldom in the arid West does the surface water supply fully coincide with the irrigation needs. Because peak streamflows from melting snows usually occur in the spring or early summer, storage works must be developed to control the flow of the streams and make the water available as needed.

Only a relatively few holdings can be served with individually developed water supplies. Most farmers must work out agreements with their neighbors as to the use of their water rights and the development of facilities to divert, convey, and distribute the water. Such arrangements usually are needed to insure that each farmer contributes his proportion of the costs of development and operation of irrigation and drainage systems. Each, furthermore, must receive his share of water at a set time and in a way that he can use it.

The quality of the water is highly important. Foreign material, whether dissolved or in solid form, may be objectionable. Excess silt, moss, sand, brush, small insects, or other debris in the water may make special treatment necessary. The treatment may consist of simple screening or may require the use of expensive sand or debris traps, depending on the kind and amount of material the water carries and the method of irrigation.

Heavy concentrations of dissolved salts are objectionable. Their total amount and kinds and the characteristics of the crops, soils, climate, and irrigation practices must all be considered in appraising water quality.

Various physical controls and structures are needed after a suitable water supply for irrigation is found. A way to control the supply and deliver it economically from the point of origin to the point of use on the farms must be made. It may include storage and diversion dams on the streams; canals and laterals to carry water to the farms; farm distribution systems; and other structures as canal linings, pumping plants, headgates, drops to control erosion, measuring devices, pipelines, siphons, check dams, and spiles.

This part of irrigation is largely engineering. It is not specifically related to the crops that are grown, except that the capacity must meet their needs. It is related to the soils only as the soils affect the stability of structures, seepage losses, and so on. Surface and underground storage reservoirs must be developed to make the natural flow of the streams correspond directly with the irrigation needs of the crops.

Preparation of irrigated land is necessary for efficient and uniform application of water regardless of the method of irrigation.

Sprinkler irrigation usually requires the least preparation, although considerable leveling is sometimes done. For good surface and subsurface irrigation, land leveling is essential. Greater efficiencies of application, more uniform distribution, ease in farming, increased production, and savings of water are among the advantages.

LAND LEVELING usually is done by tractor-drawn equipment. Some farmers prefer to do their own leveling with scrapers and levelers that can be pulled with medium-sized farm tractors, even though that takes more time than leveling by contractors who use heavy equipment.

The carryall is an efficient machine that scrapes, spreads, and transports soil. Bulldozers, graders, terracers, and maintainers are sometimes used for rough grading, but the cost of using them is higher than when a carryall is used, and only skilled operators can use them efficiently.

After the fields are rough leveled, smoothing equipment such as levelers, floats, or land planes are used to establish the final grade and finished surface. Land planes usually are more than 60 feet long and are supported at the corners by swivel wheels. A combination scraper-bucket in the center of the frame can scrape high spots and carry enough dirt to fill in low spots. Smaller levelers, usually about 30 feet long, are pulled by medium-sized farm tractors and can be used for additional smoothing operations.

Because a certain amount of soil settling always occurs on newly leveled land, it is advisable to grow a small grain or similar crop with border irrigation or a row crop with furrow irrigation after the first leveling. After harvest, the high and low spots can be releveled before a perennial crop, like alfalfa, is established.

Land leveling sometimes lowers the productivity of soils. Moving heavy equipment across fields compacts soils, especially if they are wet, and often creates a condition that is not easily remedied.

Rebuilding structure damaged by leveling operations is difficult in places where freezing and thawing do not occur. Deep-rooted legumes and grasses have been used in the Lower Rio Grande Valley of Texas to loosen surface soils and increase intake rates after fields were leveled. Rough or minimum tillage operations with alternate wetting and drying and applications of organic materials also help improve the intake rate of soil whose structure has deteriorated.

Land leveling may remove topsoil and expose subsoil. The problem is worse in the sections of higher rainfall (where soil profile development has progressed more) than in the arid regions (where cutting 1, 2, or even 5 feet into deep alluvial soils often is considered feasible). Soils with a marked development of profile often present a physical or chemical problem, or both, when the organic layer is removed in the leveling process.

When newly irrigated lands were leveled for irrigation in the Columbia River Basin, deficiencies of nitrogen, phosphorus, and zinc occurred when subsoils were exposed. Symptoms of zinc deficiency were noted first on corn and beans, but the deficiencies were found later to affect 14 other crops. On areas where surface soils were removed, fertilizers containing nitrogen, phosphorus, and zinc were applied, and production jumped from 280 to 2,280 pounds of field beans an acre.

Symptoms of a deficiency of zinc have been noted in North Dakota on corn growing on Gardena subsoils that were exposed by leveling operations. Additions of 180 pounds of nitrogen and 100 pounds of P_2O_5 with and without 15 pounds of zinc sulfate an acre increased corn forage yields 5,390 to 6,420 pounds, respectively. When no fertilizers were added, yields were 1,480 pounds an acre, compared to 7,940 pounds when those rates of nitrogen, phosphorus, and zinc, and 20 tons of manure were applied.

In a long-time experiment in Colorado, topsoil was removed to varying degrees. Liberal applications of nitrogen and phosphorus restored the productivity of Fort Collins subsoil equal to that of the original surface soil. Yields of sugar beets on check plots averaged about 7 tons an acre, compared to 20 tons on fields that got nitrogen and phosphorus. The ease with which stands were established indicated also that within a relatively short time the physical condition of the soil was as good as that of the natural surface soil.

In some localities of shallow topsoil underlain by sand or gravel, farmers have found it feasible to remove and save the topsoil, which is spread over the field again after the subsoil is leveled. This practice takes money and work, but the farmers believe many dollars can be spent to make poor land (which may nevertheless sell for 500 dollars an acre if it can be irrigated) into good land.

Leveling of land to be irrigated is not something that can be done once and then forgotten. Normal farming operations, erosion by wind and water, silting from some water supplies, and other factors tend to get the land out of level. For efficient irrigation, the grade must be uniform. Therefore some periodic floating or smoothing usually is desirable and should be considered in planning the farm operations and equipment needs.

Because a smooth land surface is desirable for spreading water over the field, some farmers tend to overtill their fields. Soils high in silt soon lose their structure under continuous tillage. The density of soil is increased by running tractors over it. Although maximum compaction might be obtained by working the soils while wet, working some soils when dry forms a dust, which lowers the intake rate. Most irrigated soils therefore should be tilled no more than absolutely necessary to prepare the seedbed, control weeds and insects, and ready it for irrigation. All other tillage merely costs the farmer money, makes it harder to get water into the soil, and lowers production because it impedes movement of soil water and air.

THE THREE GENERAL METHODS of applying water to cropland are surface irrigation, sprinkler or overhead irrigation, and subsurface irrigation.

Whatever the method, the aim is to apply adequate water to the soil uniformly over the field with no harm to the crop or the soil and with a minimum of water and labor.

In surface irrigation, the water may completely cover the surface (commonly called flood irrigation) or it may flow in furrows or small ditches. Either method may be used on sloping or relatively flat lands.

Flood irrigation includes border irrigation (running water downslope between dikes), and basin irrigation (quickly ponding water on a level area), and flooding downslope from the contour ditches.

For border irrigation, the slope of the land down the strip generally should not be less than 0.1 percent and not more than 2 percent, although slopes exceeding 6 percent have been used for narrow border strips planted to grass or dense cover crops. If crops are to be established on steeper slopes, sprinkler irrigation should be used to prevent erosion unless rainfall is adequate to start the crop. Cross slope within the strip is not permitted.

In basin irrigation, water is applied quickly to a flat area surrounded by dikes. A relatively large stream is used. The water is ponded on the basin area and continues to percolate into the soil some time after the stream has been turned off.

Level basin irrigation for both close-growing and the row crops has been gaining favor in the Lower Rio Grande Valley. Farmers who have invested approximately 100 dollars an acre to install such systems say that increased production has repaid the investment in 2 or 3 years. Greater production has come from more uniform distribution of water and control of excess salts.

With level basin irrigation, each plant in the row receives its share of the water applied. Less labor is required. The amount of water applied can be more easily controlled. Because no runoff occurs, knowing the size of irrigation stream and the duration of application makes possible efficient applications without detailed knowledge of soil intake rates which is necessary for efficient irrigation on graded land. Also, more of the precipitation falling on the area may be retained and made effective in meeting the water requirement of the crop.

Considerable interest has developed in level contour bench irrigation on land slopes up to 5 percent in the High Plains of Texas. This system allows for more efficient use of limited supplies of ground water through maximum utilization of rainfall without surface runoff. Impounded water remains on the level strips laid out on the contour until it is absorbed by the soil or (in case of excess amounts from heavy storms) is removed by surface drainage facilities.

One farmer remarked, "My land will be ready for productive dry-farming when the irrigation well is dry." From the standpoint of maximum utilization of rain, his statement is no doubt correct.

Level contour bench systems have

been studied at Mitchell, Nebr., as a possible way to prevent severe erosion on irrigated slopes adjoining river bottom lands. Severe damage to irrigation and drainage structures has occurred in western Nebraska from runoff that accumulates in small watersheds above the irrigated project. Attention also has been given to a method of removing and storing topsoil for subsequent replacement on the leveled benches.

Flooding from contour ditches has been used a great deal on rather steeply sloping lands. The water is allowed to flow as a sheet downslope between field ditches that are closely spaced and on the contour. The ditches distribute the water through frequent openings and also capture runoff from the field above and redistribute it. This method is not considered efficient in the use of labor or water.

Both the border and the basin methods require the use of farming practices that leave the dikes intact so the boundaries of the strips need not be changed frequently. Once the land is leveled to meet the requirements for the type of irrigation chosen, the farmer will not want to unlevel the land by improper tillage practices. Also, because good irrigation depends on storing needed water in the soil, he will not want to use practices that will change greatly the structure and intake rate of his soil.

The soil is not only the moisture storage reservoir. Under surface irrigation it is also the channel that conveys water from the upper end to the lower end of the field. Intake rates that are too slow or too rapid therefore are not suitable for surface irrigation.

Proper irrigation and efficient use of water is difficult to attain when soils absorb water at rates less than 0.1 inch an hour. Irrigation by surface methods becomes impractical when rates of intake exceed 3 inches an hour. The usable water-holding capacities of these soils with high intake rates are often so low, however, that the soils are too droughty for most agriculture.

Sprinkler, or overhead, irrigation is adapted to most soils and crops. It provides excellent control of the water and can be turned off when the soil has absorbed the required amount. The rate of application should be no greater than the amount the soil can absorb without surface runoff. Such good control of water makes it possible to use sprinkler irrigation for a number of special purposes, such as to establish new seedings on steeper lands or on permeable soils that will be irrigated later by another method.

Sprinkling requires less land smoothing. Less care is needed to keep the surface level. On the tighter soils or those readily compacted or puddled, care must be taken to see that the farm operations do not compact the soil until the intake rate is reduced below the rate at which sprinklers apply the water.

In subsurface irrigation, an artificial water table is created and maintained at a predetermined depth below the surface within reach of plant roots. Moisture is supplied to the plant roots through upward capillary movement. The depth to water must be controlled carefully; otherwise the depth can become too small or too great and may retard or stop root growth.

Certain special management practices seem necessary where subirrigation is practiced in the West. Special provisions—the temporary use of sprinklers or local surface irrigation—may be required to get seed germinated and the seedlings started. Also, when the underground water contains appreciable quantities of salts and fluctuates regularly in a soil, an impervious layer, or lens, of salt tends to develop and may retard the movement of the water. The lens is usually just a little below the level at which the "sub" (water table) is generally maintained. Deep chiseling to shatter the lens may be desirable.

When precipitation is light, an annual surface irrigation during the period when the water table is low may be necessary to leach out the salts. Since the soil must be highly permeable for satisfactory subsurface irrigation, careful management of fertilizers may be necessary, especially if precipitation is heavy in winter or if excessive surface irrigation is practiced for leaching purposes or to get the crop started.

Surface irrigation may be 50 to 90 percent efficient. Efficiencies of sprinkler applications normally are 70 to 80 percent. Thus more irrigation water must be made available to the farm than will actually be consumed by the crops. The amount of excess will depend on the efficiency with which the water can be applied.

EFFICIENCY OF IRRIGATION is affected by topography and soil and crop conditions.

The design of the irrigation system, the degree of land preparation, and the skill and care of the irrigator, however, probably have the greatest influence on the efficiency and total amount of water that must be delivered to the farm headgate.

Efficiencies of 100 percent in applying irrigation water are not possible with present irrigation facilities and practices. More water is applied at some spots in the field than in others. Some water is usually lost by deep percolation. Frequently some surface runoff occurs. This is not entirely undesirable, however, because some excess water must move downward through the soil to prevent a harmful accumulation of salts near the surface of the land. The amount of deep percolation required for this purpose seldom exceeds 15 to 20 percent of the water.

The factors that govern the selection of an irrigation system should be considered not only as they exist at the time the system is planned but as they will be modified under improved management practices.

Some irrigation systems are better adapted to growing certain types of crops than others. Close-growing crops, such as alfalfa and pastures, are usually flood irrigated. Row crops, like corn, cotton, and sugar beets, are furrow irrigated. Rotation from row crops to cover crops is common, and plans should be made to irrigate by several methods. Seldom nowadays is land planted to a single crop year after year.

Topography and slope greatly influenced the choice of irrigation method in the past. New earth-moving equipment now makes it feasible to modify land surfaces to almost any condition desired. Consideration must be given, however, to cost and benefits in relation to soil conditions and crops to be grown before modification of the land surface is made and the method of application selected.

The most important soil characteristics that influence the choice of irrigation are the usable depth of water that can be stored in the root zone of the crop and the erodibility and the intake rate of the soil. Each of these factors can be changed greatly by the type of soil management. For example, deep plowing to disrupt a plowpan, combined with minimum tillage operations, will usually increase intake rates and depth of root penetration.

Water supply also is important in choosing a system of irrigation. Small, constant-flow streams may be more adaptable to sprinkler irrigation, but large, intermittent streams, particularly if storage facilities are not present, often can be used better by surface irrigation methods.

Intensity of rainfall must be considered in the design of irrigation systems.

In the Northwest, where rains are gentle, little attention need be given to erosion from irrigated fields because of rain. In the Southwest, where cloudbursts occur, rainfall must be taken into account in laying out irrigation systems and fields.

The irrigation system may be used only once or twice a year if summer precipitation is heavy. Certainly this will affect the choice of methods. Also, in areas of heavier precipitation it is often found desirable to level the land so that excess waters can be removed in the winter and early spring. Once the land is properly leveled for drainage, little extra effort or expense is needed to prepare it for various methods of surface irrigation.

Removal of excess irrigation water from irrigated lands usually is necessary. High water tables are caused by losses that occur in storage and conveyance of water to the point where it can be utilized; by the relatively low irrigation application efficiencies resulting from deep percolation losses and runoff; and from excess water applications required to maintain a favorable salt balance in the surface soil.

Subsurface drainage is required if soils become waterlogged. Root development is restricted because of inadequate aeration. Soils are slow to warm up in the spring. Seed germination is delayed. High water tables can result also in the accumulation of excess salt in the surface soil. That adversely affects soil structure and reduces intake rates and the availability of moisture to the plant.

The water table must be held low enough to provide adequate removal of water from the crop root zone and prevent upward movement of salts into the root zone from the more saline ground water. Since soil is farmed to greater depths in the West than in the East, drains must be installed deeper. It is not uncommon therefore to have open ditches or tile drains as deep as 8 to 10 feet in many western irrigated projects to accommodate crops with deep roots. Roots of the same crops grown in humid areas usually are restricted to the upper 2 or 3 feet because of poorer subsoil conditions.

Excess water on higher land may waterlog the lower lands. An extensive system of drains may be necessary to correct that. Lands once waterlogged often are never fully productive again. On the field itself, poor distribution and inefficient use of water sometimes show up in poor yields at the top and bottom of the field and fairly good yields at the center: The upper end gets too much water and loses plant food by leaching and erosion, and plants at the lower end get too little water for proper growth.

Good surface drainage is also essential for top crop yields. Most crops will not live very long in standing water, especially during hot weather. Whether the water comes from rainfall or irrigation, the results are the same—excess water must be removed quickly and safely.

Not all irrigated lands are readily subject to damage from ponded surface waste water. The coarser textured flat lands absorb water rapidly. On the tighter and steeper lands, however, irrigation without surface waste by any method is difficult, and most of the rain that falls may be lost in runoff.

High water tables or accumulation of excess salt have occurred in parts of nearly every irrigated project in the West. Development of drainage systems concurrently with land development of an irrigated project usually prevents trouble.

Another serious problem in the West is how to apply irrigation water to crops without washing away soil. Anything done to improve the structure of the soil usually increases the rate at which the irrigation water is absorbed. An increase in the rate of intake means that larger irrigation streams must be delivered to the fields.

Even though the erodibility of the soil may be reduced somewhat by proper soil management, the effect of the larger streams more than offsets any gain in stability of the soil. Although an improvement in soil structure usually makes necessary a larger irrigation stream, increasing the effective depth of the root zone tends to allow the use of smaller streams.

Water applied to soil immediately after plowing or cultivation causes breakdown of clods and filling of larger pore spaces with soil particles lubricated and made buoyant by water. Water thus tends to settle, or compact, the soil and to increase its density. Gradual consolidation of the cultivated surface continues for several irrigations, after which it becomes more or less stable. With further irrigation, increased intake rates can occur because plant foliage and crop residues usually reduce the velocity of flowing water and increase the wetted areas.

Investigations at Prosser, Wash., have shown that an eightfold variation of furrow intake rates occurred within a given season. This is in addition to variations that occur from season to season, depending on previous crop history, the crop irrigated, moisture content of soil, cultivation, and stream.

Irrigation water applied improperly also causes segregation of the soil particles. The smaller particles are moved downslope and tend to increase the intake rate at the upper end and seal off the lower end of the field. Uniform irrigation throughout the field thus is harder to achieve. Proper irrigation and soil management will help prevent particle segregation.

Uncontrolled irrigation water can cause erosion. It can strip soil from bare sloping fields at an alarming rate: The very water that is so essential to crop growth can also be the means by which the land is ruined.

Changes in absorption rate of soil during the cropping sequence must be kept in mind when the system is designed. Obviously, water need not be in contact with the soil for as long a time when the absorption rate is high as when it is lower to store the same amount of water.

Thus, for the more permeable soils, irrigation streams should be large but should be applied for a short time. Thus the irrigator can get the water across the field rapidly so that no more is absorbed than is desired for good irrigation.

Also (since the rate at which the soil absorbs water declines with time), the shallower the irrigation, the larger the stream needed but for a shorter period of time. Thus, the faster the intake rate of the soil and the less depth applied each irrigation, the larger the stream must be.

When sprinklers are used, the intake rate of the soil governs the size of the stream only as far as the maximum intake rate of the soil is concerned. If water is applied faster than the soil will absorb it, losses of water will occur by surface runoff.

Equally important is the management of irrigation water for good crop production after it has reached the farm. When to irrigate and how much water to apply are questions that continually confront the farmer.

Excessive use of water often can aggravate a drainage problem and reduce yields by allowing deep percolation and leaching of soluble nutrients below root depths. Proper scheduling of irrigations to maintain soil moisture conditions for continuous growth of the plant is important.

To do a good job of irrigating, a farmer needs to know something about how much water is needed to grow a crop; the amount of water that can be stored in the soil-root reservoir; how much of the stored water that can be used before reapplying water; the amount of water withdrawn by the crop at the time he irrigates; and the length of time that water must be in contact with the soil to replace the amount used.

The farmer can eliminate some of the guesswork involved in water management by using the irrigation guides of the Department of Agriculture.

The formulation of irrigation guides requires information about the amount and the rate that crops use water. This phenomenon is referred to as consumptive use or evapotranspiration—the water transpired and evaporated from a given area—and is an important element in the hydrologic cycle of water movement from the time it falls on the land until it returns to the atmosphere or reaches the ocean. It is the best index of how much water will be needed to produce good crops.

Measurements of consumptive use of water by various crops and natural vegetation have been made under many different physical and climatic conditions. Methods have been developed to estimate consumptive use for a given locality, based on a correlation of climatological data with actual measurements. These methods give the total consumptive requirement of the crop regardless of the source of the water.

In areas where ground water is not a major contributor, the amount of water that must be supplied by irrigation depends on how much precipitation can be utilized to meet the consumptive needs of the crops. The contribution may vary from practically nothing (as at Yuma, Ariz.) to all crop needs.

How nearly precipitation meets the needs of the crops depends on the annual amount of precipitation and on the time and way it occurs. It also depends on how much water can be stored as soil moisture in the root zone of the crop at any time. The usable amount varies from place to place and with crop and soil conditions. The more precipitation the root zone of the crop absorbs and stores, the less irrigation water will be required. Thus the consumptive use of the crop minus the effective rainfall gives the net irrigation water requirement.

Values of normal consumptive use of water by each of the major crops and effective rainfall are available for each irrigated area of most States of the West through publications of the State experiment stations or the Soil Conservation Service.

The depth of water required in each irrigation depends on how large the soil moisture reservoir is and how nearly it can be emptied between each irrigation. A medium-textured soil normally stores about 2 inches of usable water per foot of depth of soil. Not all of that water should be removed before irrigating again, however. Usually not more than about 1 inch is removed if the crop is to grow most rapidly. Thus, if the root zone of the crop is 3 feet deep, about 3 inches of water should be stored each irrigation. A farm efficiency of 75 percent would require that 4 inches of depth or 4 acre-inches per acre should be delivered to the farm headgate for the irrigation. Assuming a medium rate of use of water by the plants of 0.2 inch a day, the 3 inches stored would last 15 days, or the irrigation interval would be every 2 weeks.

The time required to apply an average of 4 acre-inches per acre would depend upon the size of the stream delivered to the farm and the acreage to be irrigated. A stream of 1 cubic foot a second (1 c.f.s.) is approximately equivalent to 1 acre-inch of water an hour. Thus, if the irrigating stream is 4 c.f.s., an average depth of 4 inches could be applied to an acre each hour. At 75 percent efficiency, 3 inches of depth or more would be stored in the crop root zone.

Plants do not withdraw moisture at equal rates from all depths of the root zone. Much of the greatest use is from the top half of the root zone depth. When all available moisture is extracted from any appreciable part of the root zone, growth slows down. Thus irrigation often is considered desirable while 35 percent to 50 percent of the total available moisture is still left in the root zone. An example: A 4-foot root zone that could store 2 inches of usable water per foot of depth would mean that irrigation should start when about 4 inches (or not more than 5 inches) had been used by the crop.

The amount of available moisture that a soil can store for plant use influences the frequency, size of streams, size of farm laterals, and other elements of design. In general, inches of available moisture that can be stored in a foot of sand range from 0.25 to 0.75; loamy sands, 0.75 to 1.25; sandy loams, 1.00 to 1.50; fine sandy loams, 1.50 to 2.00; clay loams, 1.75 to 2.25; and clays, 2.00 to 3.00.

Some plants go deeply into the soil. Others have shallow roots. If the roots can extract water from as deep as 6 feet, instead of only 3 feet, it will be more efficient to apply more water at each irrigation and the irrigations will be less frequent. With the greater depths of water applied at each irrigation to the deeper rooted crops, lengths of irrigation run can be greater or the size of irrigation streams may be smaller and still give efficient irrigation.